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(54) **ELECTRON EMISSION DEVICE AND ELECTRON EMISSION DISPLAY**

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H01B 1/04	(2006.01)
H01J 1/312	(2006.01)
H01J 31/12	(2006.01)

(52) **U.S. Cl.**

CPC . ***H01J 29/04*** (2013.01); ***H01B 1/04*** (2013.01); ***H01J 1/312*** (2013.01); ***H01J 29/18*** (2013.01); ***H01J 31/127*** (2013.01)

(58) **Field of Classification Search**

CPC H01J 1/308; H01J 1/304; H01J 1/312; H01J 31/127

USPC 257/10

See application file for complete search history.

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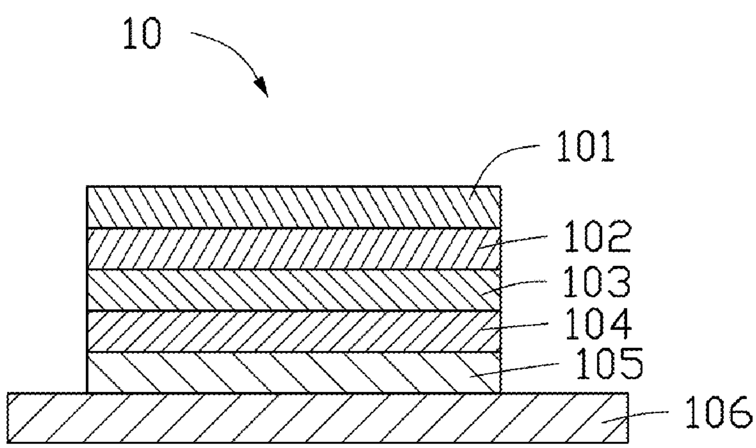
(57) **ABSTRACT**

An electron emission device includes a number of second electrodes intersected with a number of first electrodes to define a number of intersections. An electron emission unit is sandwiched between the first electrode and the second electrode at each of the number of intersections, wherein the electron emission unit includes a semiconductor layer, an electron collection layer, and an insulating layer stacked together, and the electron collection layer is a conductive layer.

19 Claims, 15 Drawing Sheets



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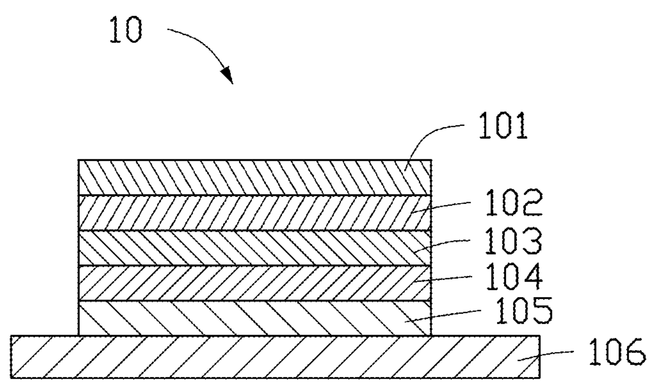

FIG. 1

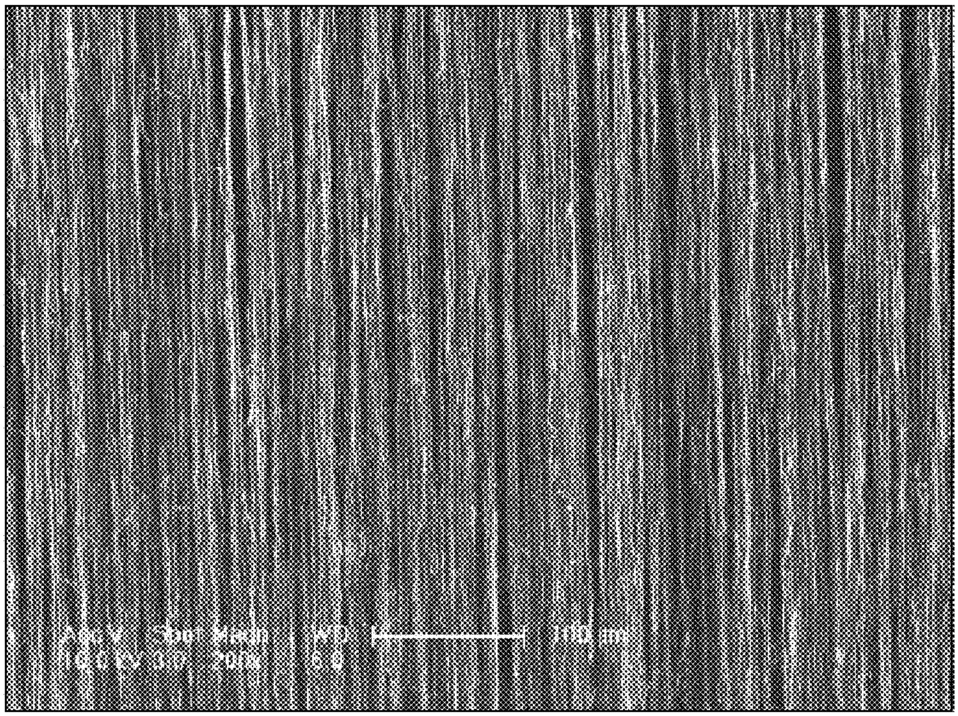

FIG. 2

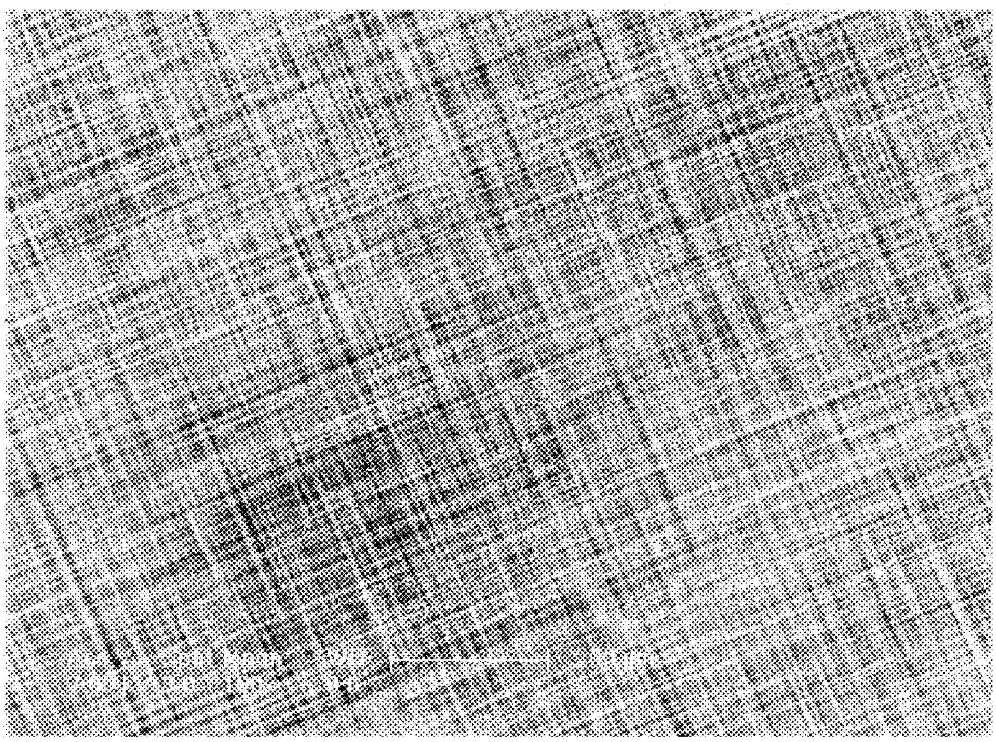

FIG. 3

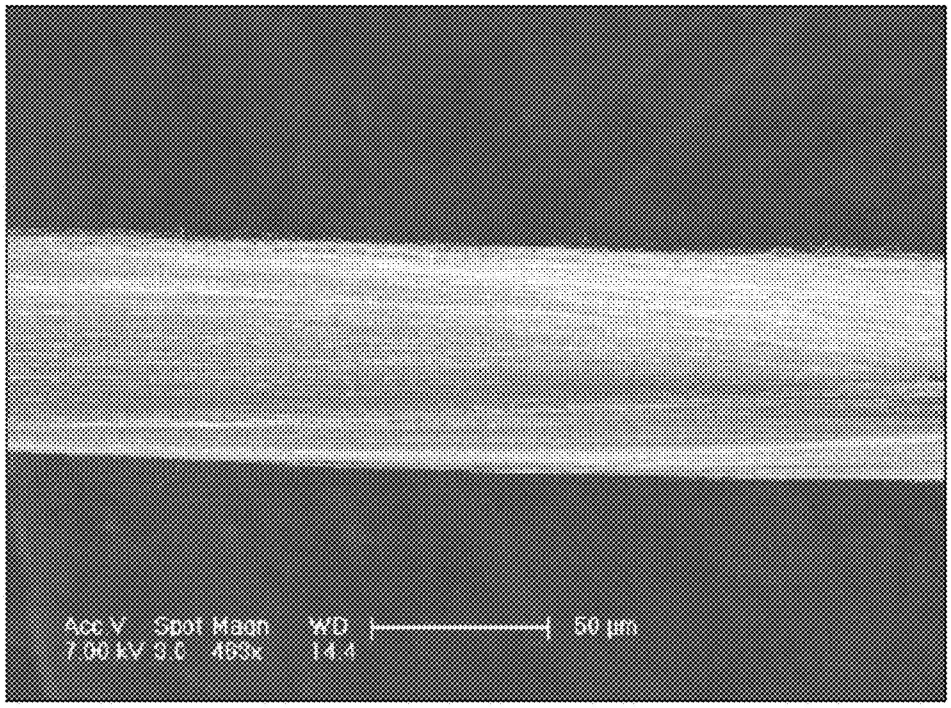

FIG. 4

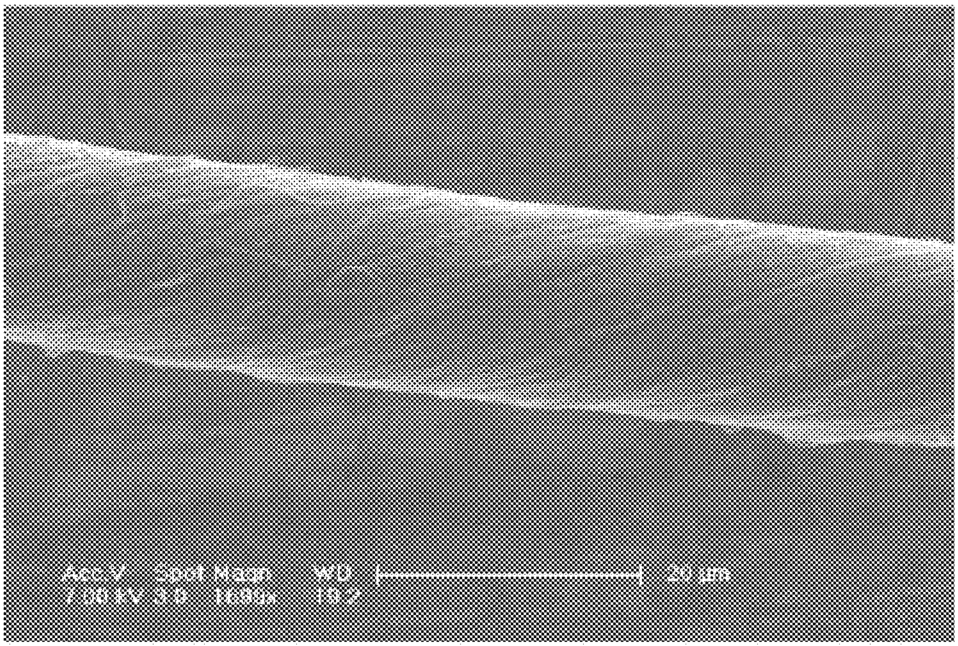

FIG. 5

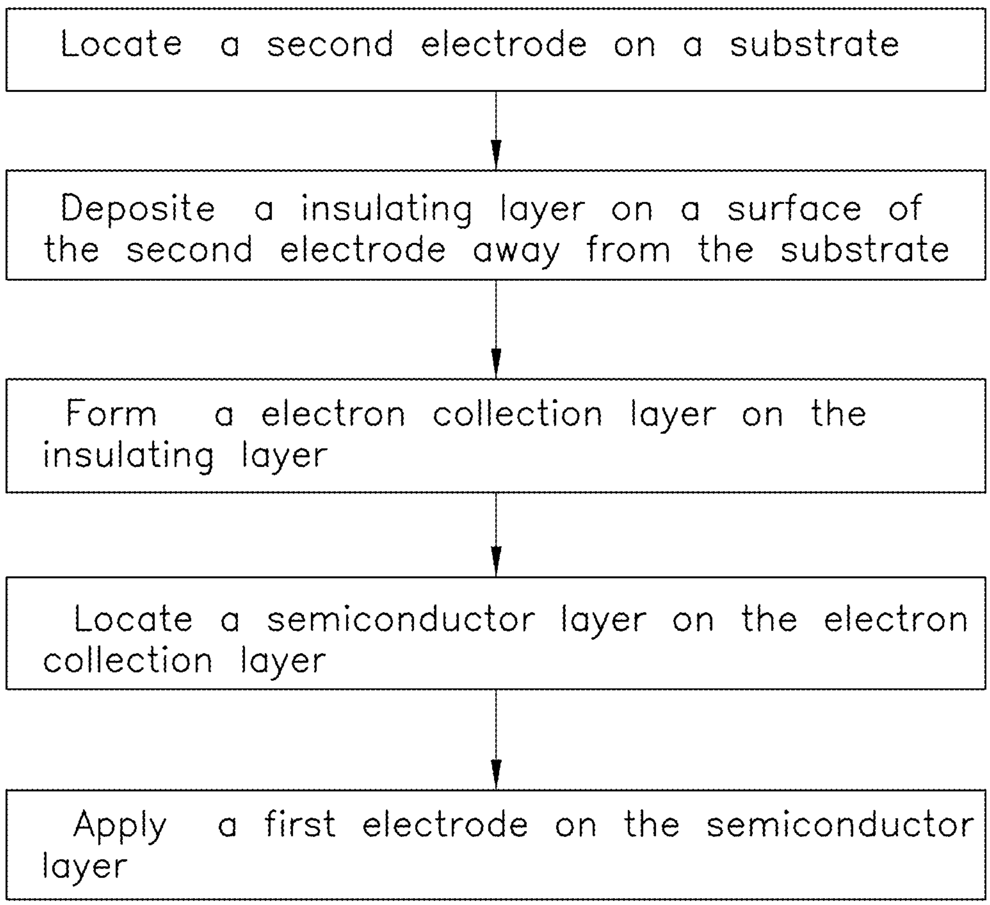
Locate a second electrode on a substrate
Deposite a insulating layer on a surface of the second electrode away from the substrate
Form a electron collection layer on the insulating layer
Locate a semiconductor layer on the electron collection layer
Apply a first electrode on the semiconductor layer

FIG. 6

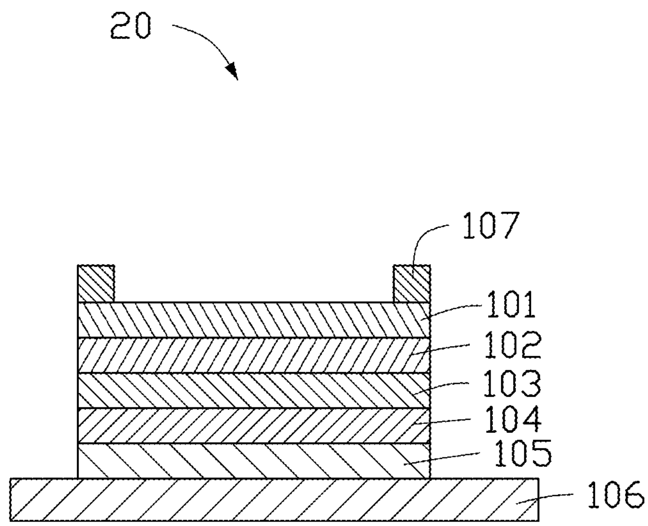

FIG. 7

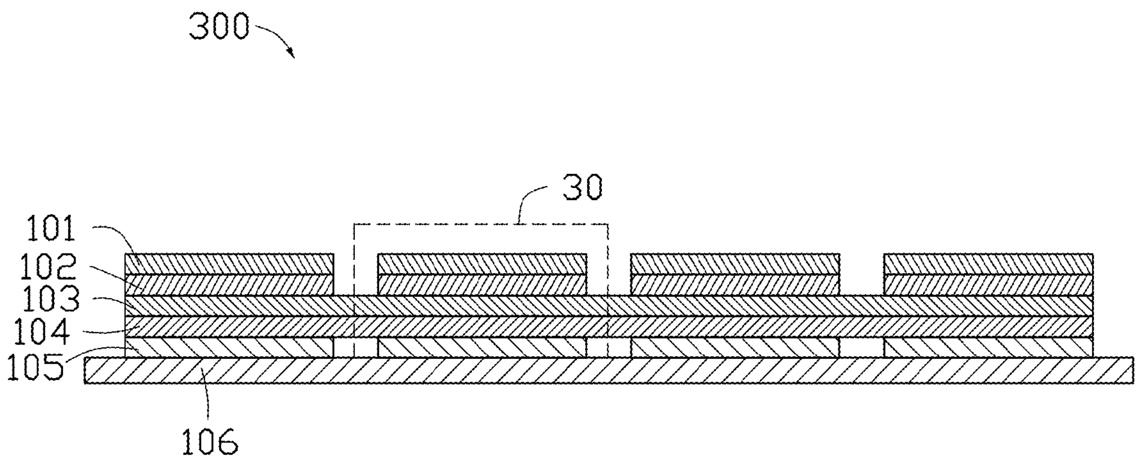

FIG. 8

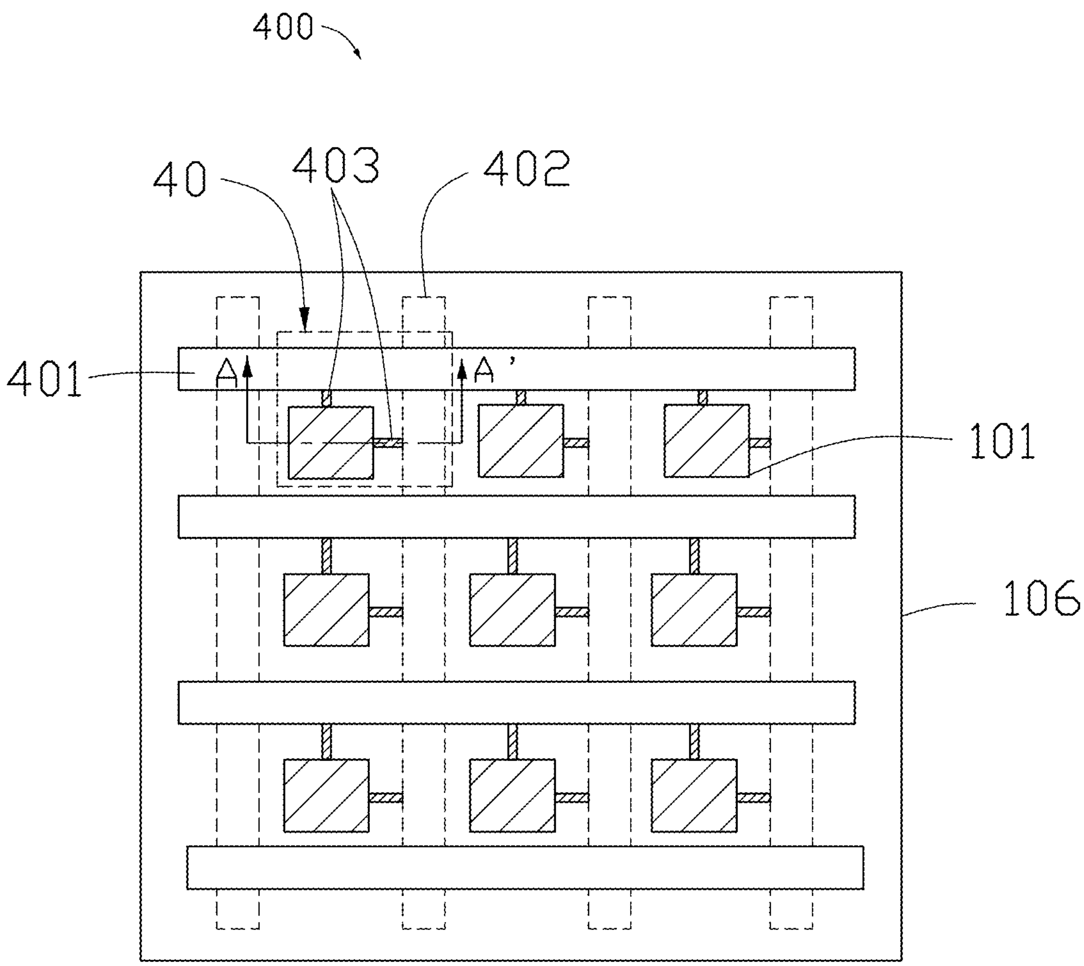

FIG. 9

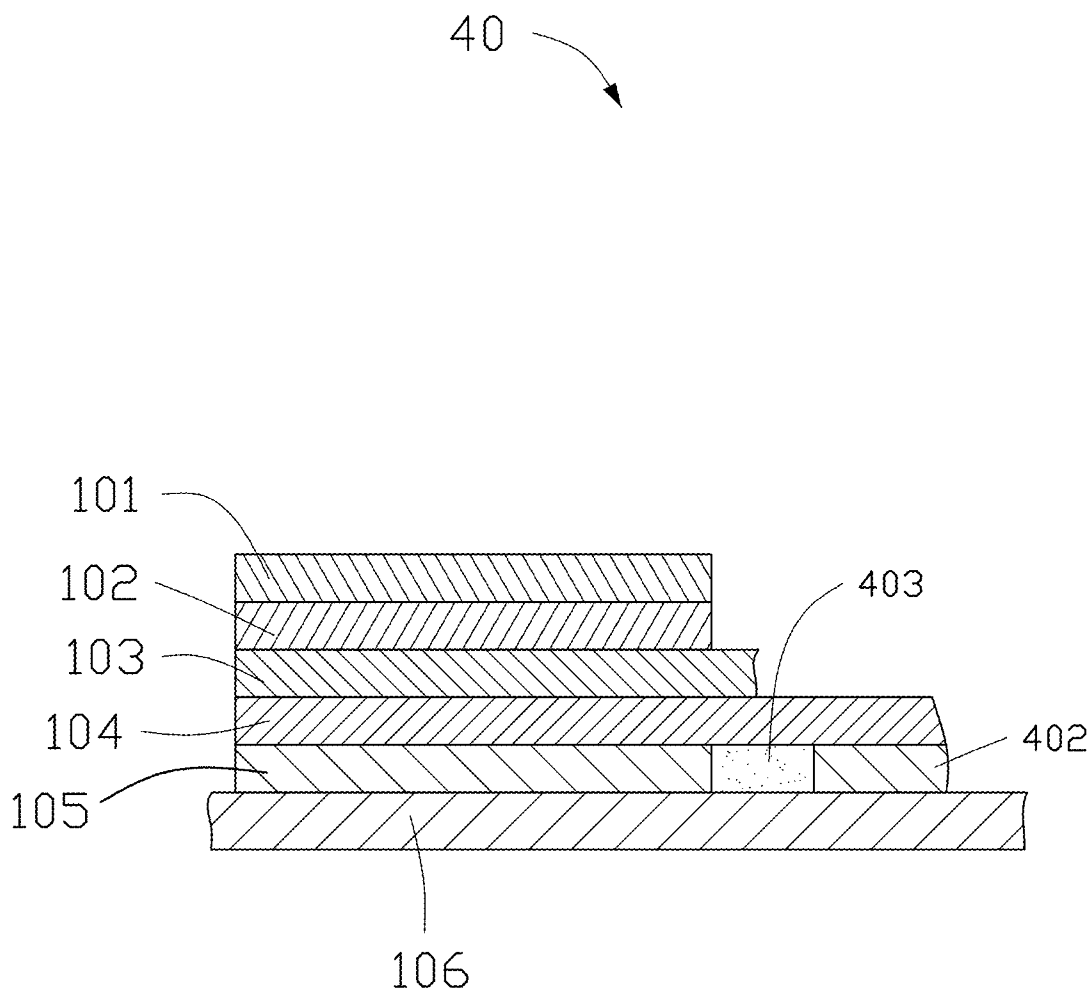

FIG. 10

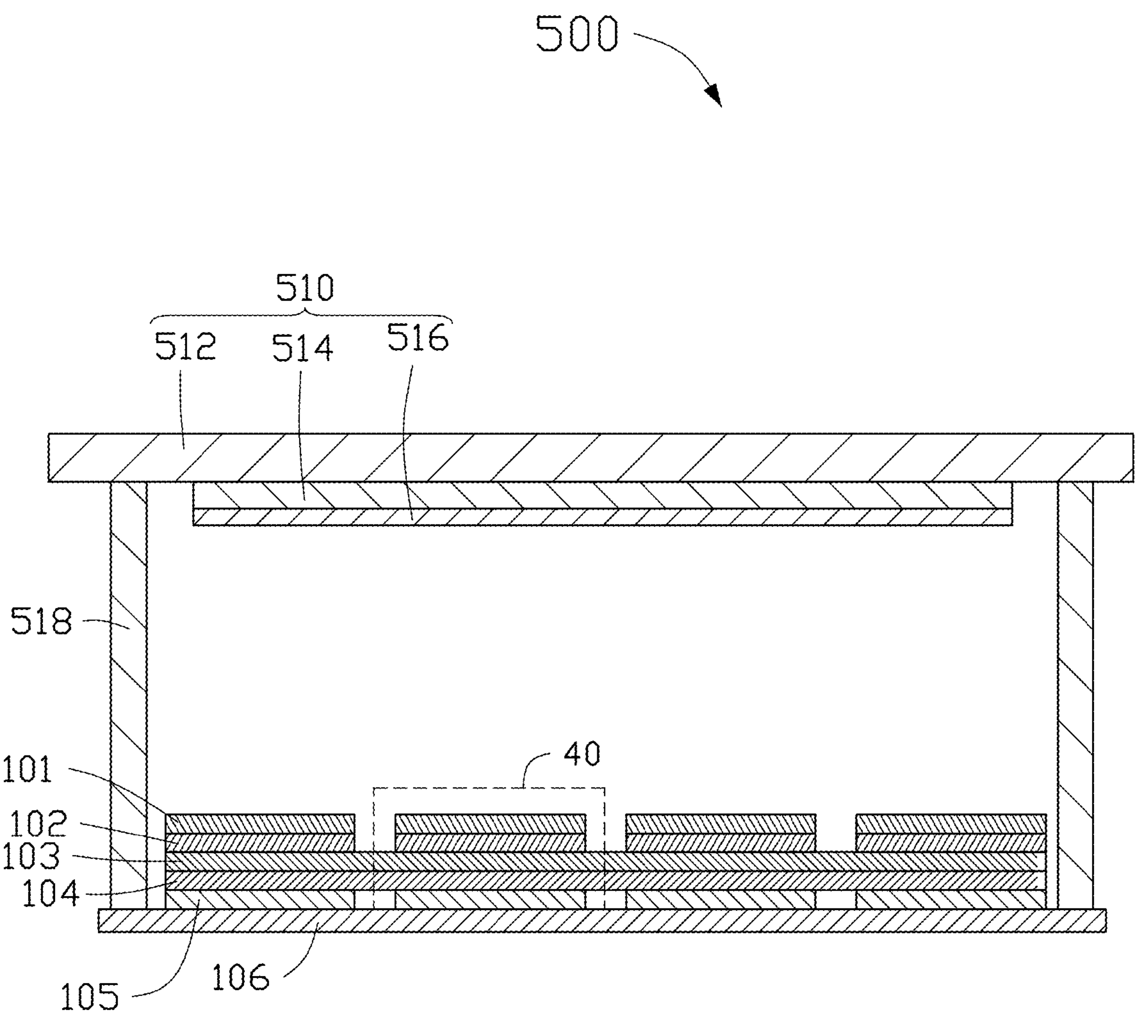

FIG. 11

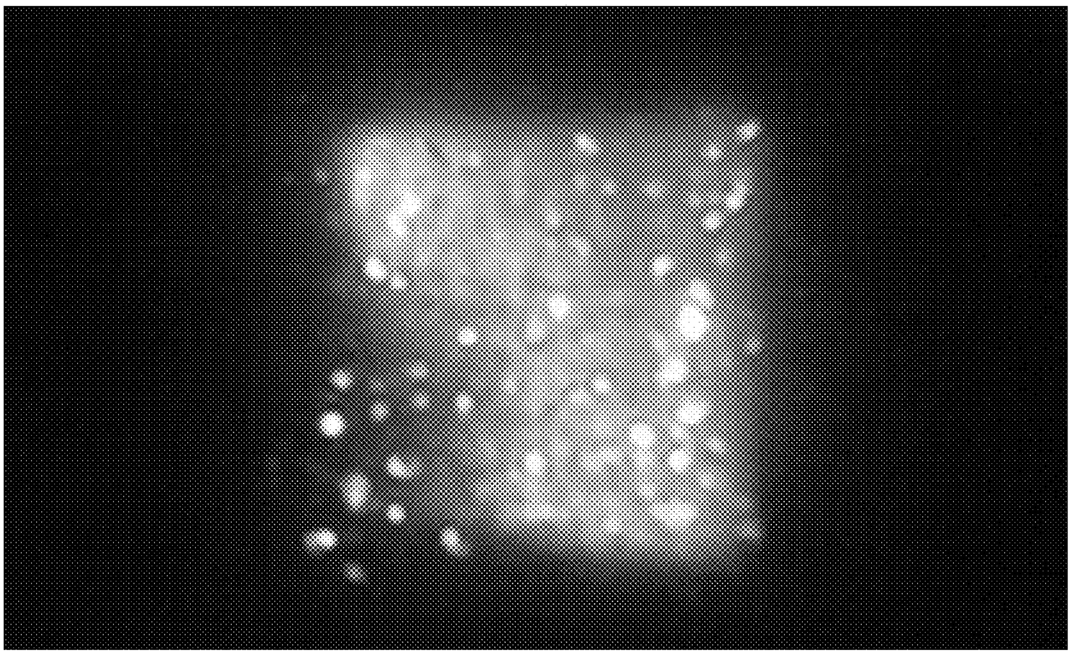

FIG. 12

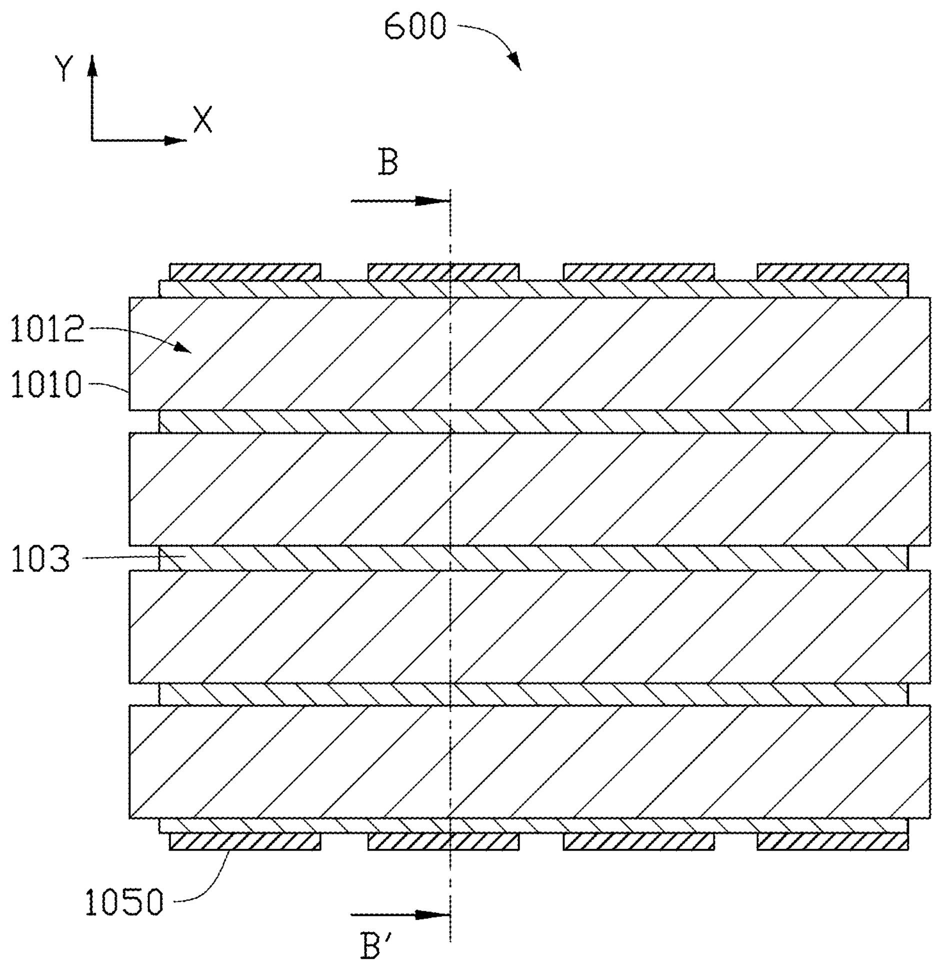

FIG. 13

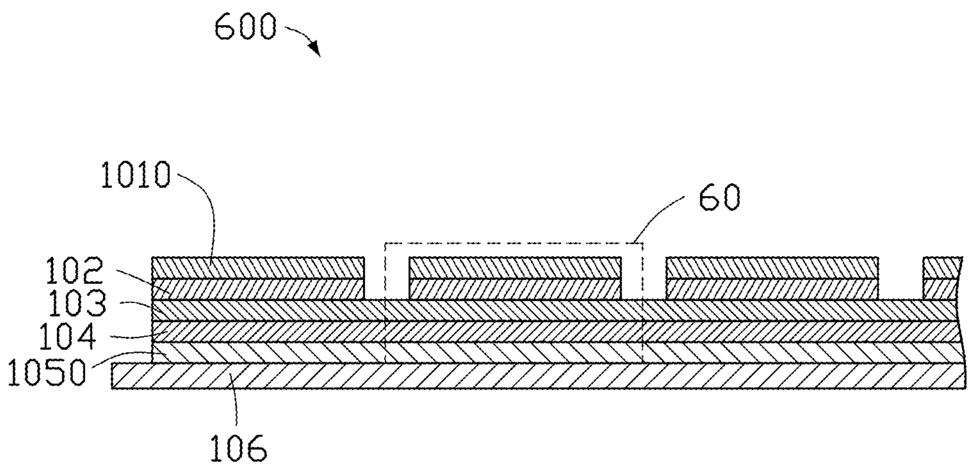

FIG. 14

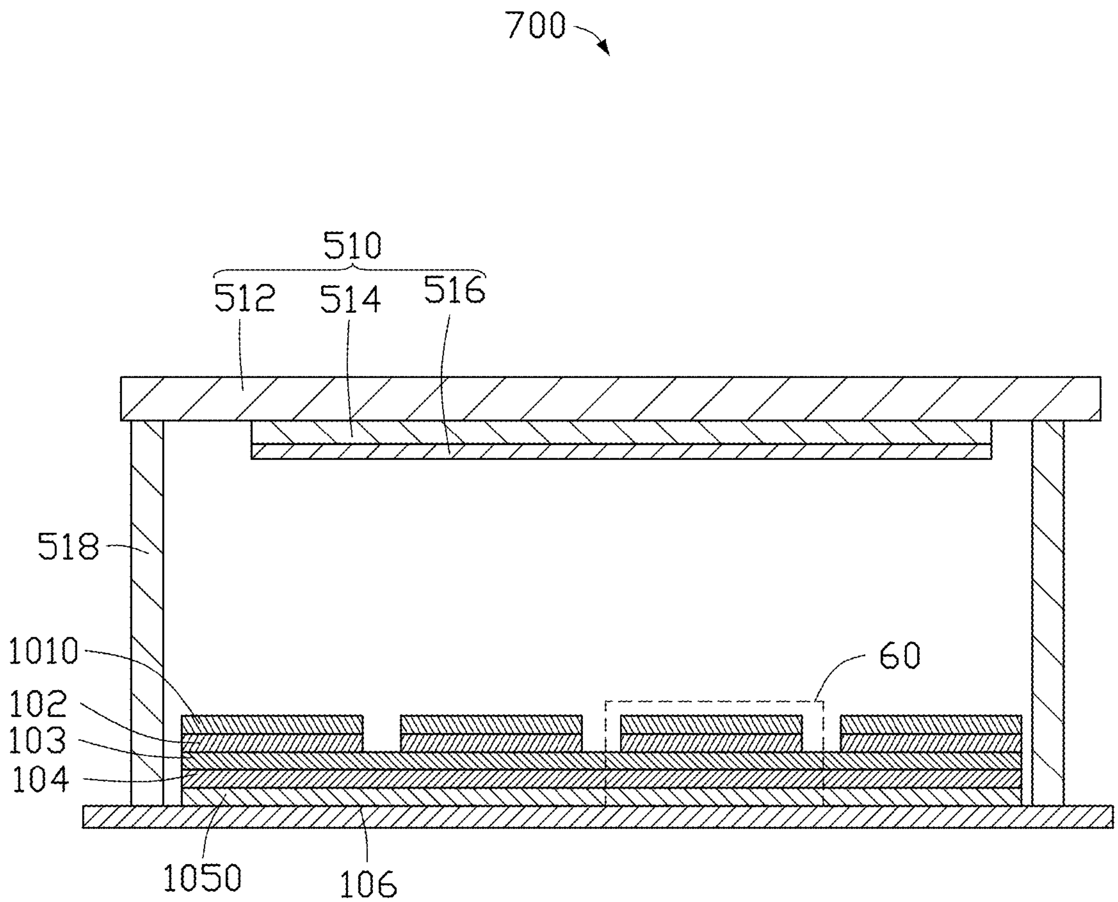

FIG. 15

ELECTRON EMISSION DEVICE AND ELECTRON EMISSION DISPLAY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims all benefits accruing under 35 U.S.C. §119 from China Patent Application 201410024482.4, filed on Jan. 20, 2014 in the China Intellectual Property Office, disclosure of which is incorporated herein by reference.

BACKGROUND

1. Technical Field

The present disclosure relates to an electron emission source, an electron emission device, and an electron emission display with the electron emission device, especially a cold cathode electron emission device with carbon nanotubes and the electron emission display with the same.

2. Description of Related Art

Electron emission display device is an integral part of the various vacuum electronics devices and equipment. In the field of display technology, electron emission display device can be widely used in automobiles, home audio-visual appliances, industrial equipment, and other fields.

Typically, the electron emission source in the electron emission display device has two types: hot cathode electron emission source and the cold cathode electron emission source. The cold cathode electron emission source comprises surface conduction electron-emitting source, field electron emission source, metal-insulator-metal (MIM) electron emission sources, and metal-insulator-semiconductor-metal (MISM) electron emission source, etc.

In MISM electron emission source, the electrons need to have sufficient electron average kinetic energy to escape through the upper electrode to a vacuum. However, in traditional MISM electron emission source, since the barrier is often higher than the average kinetic energy of electrons, the electron emission in the electron emission device is low, and the display effect of the electron emission display is not satisfied.

What is needed, therefore, is to provide an electron emission source, an electron emission device, and electron emission display that can overcome the above-described shortcomings.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the embodiments can be better understood with reference to the following drawings. The components in the drawings are not necessarily drawn to scale, the emphasis instead being placed upon clearly illustrating the principles of the embodiments. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. **1** shows a schematic view of one embodiment of an electron emission source.

FIG. **2** shows a Scanning Electron Microscope (SEM) image of carbon nanotube film.

FIG. **3** shows a SEM image of a stacked carbon nanotube film structure.

FIG. **4** shows a SEM image of untwisted carbon nanotube wire.

FIG. **5** shows a SEM image of twisted carbon nanotube wire.

FIG. **6** shows a flowchart of one embodiment of a method of making electron emission source.

FIG. **7** shows a cross-section view of another embodiment of an electron emission source.

FIG. **8** shows a cross-section view of another embodiment of an electron emission device.

FIG. **9** shows a schematic view of another embodiment of an electron emission device.

FIG. **10** shows a cross-section view of the electron emission device along a line A-A' in FIG. **9**.

FIG. **11** shows a schematic view of one embodiment of an electron emission display.

FIG. **12** shows an image of display effect of the electron emission display in FIG. **11**.

FIG. **13** shows a schematic view of another embodiment of an electron emission device.

FIG. **14** shows a cross-section view of the electron emission device along a line B-B' in FIG. **13**.

FIG. **15** shows a schematic view of another embodiment of an electron emission display.

DETAILED DESCRIPTION

The disclosure is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to "an" or "one" embodiment in this disclosure are not necessarily to the same embodiment, and such references mean at least one.

Referring to FIG. **1**, an electron emission source **10** of one embodiment comprises a first electrode **101**, a semiconductor layer **102**, an electron collection layer **103**, an insulating layer **104**, and a second electrode **105** stacked in that sequence. The first electrode **101** is spaced from the second electrode **105**. A surface of the first electrode **101** is an electron emission surface to emit electron.

Furthermore, the electron emission source **10** can be disposed on a substrate **106**, and the second electrode **105** is applied on a surface of the substrate **106**. The substrate **106** supports the electron emission source **10**. A material of the substrate **106** can glass, quartz, ceramics, diamond, silicon, or other hard plastic materials. The material of the substrate **106** can also be resins and other flexible materials. In one embodiment, the substrate **106** is silica.

The electron collection layer **103** is sandwiched between the insulating layer **104** and the semiconductor layer **102**. The first electrode **101** is located on the semiconductor layer **102**. The first electrode **101** is insulated from the second electrode **105** by the insulating layer **104**. The electron collection layer **103** collects and storage the electrons. The semiconductor layer **102** accelerates the electrons, thus the electrons can have enough energy to escape from the first electrode **101**.

A material of the insulating layer **104** can be a hard material such as aluminum oxide, silicon nitride, silicon oxide, or tantalum oxide. The material of the insulating layer **104** can also be a flexible material such as benzocyclobutene (BCB), acrylic resin, or polyester. A thickness of the insulating layer **104** can range from about 50 nanometers to 100 micrometers. In one embodiment, the insulating layer **104** is tantalum oxide with a thickness of 100 nanometers.

The semiconductor layer **102** is sandwiched between the first electrode **101** and the electron collection layer **103**. The semiconductor layer **102** plays a role of accelerating electrons. The electrons are accelerated in the semiconductor layer **102**. A material of the semiconductor layer **102** can be a semiconductor material, such as zinc sulfide, zinc oxide, magnesium zinc oxide, magnesium sulfide, cadmium sulfide, cadmium selenide, or zinc selenide. A thickness of the semiconductor layer **102** can range from about 3 nanometers to about 100 nanometers. In one embodiment, the material of the semiconductor layer **102** is zinc sulfide having a thickness of 50 nanometers.

The electron collection layer **103** is sandwiched between the semiconductor layer **102** and the insulating layer **104**. The electron collection layer **103** is a conductive layer comprising a conductive material. The material of the electron collection layer **103** can be gold, platinum, scandium, palladium, hafnium, or other metal or metal alloy. Furthermore, the material of the electron collection layer **103** can also be carbon nanotubes or graphene. A thickness of the electron collection layer **103** can range from about 10 nanometers to about 1 micrometer.

In one embodiment, the electron collection layer **103** can comprise a carbon nanotube layer. The carbon nanotube layer comprises a plurality of carbon nanotubes. The carbon nanotubes in the electron collection layer **103** extend parallel to the surface of the electron collection layer **103**.

The carbon nanotube layer includes a plurality of carbon nanotubes. The carbon nanotubes in the carbon nanotube layer can be single-walled, double-walled, or multi-walled carbon nanotubes. The length and diameter of the carbon nanotubes can be selected according to need. The thickness of the carbon nanotube layer can be in a range from about 10 nm to about 100 μm, for example, about 10 nm, 100 nm, 200 nm, 1 μm, 10 μm or 50 μm.

The carbon nanotube layer forms a pattern. The patterned carbon nanotube layer defines a plurality of apertures. The apertures can be dispersed uniformly. The apertures extend throughout the carbon nanotube layer along the thickness direction thereof. The aperture can be a hole defined by several adjacent carbon nanotubes, or a gap defined by two substantially parallel carbon nanotubes and extending along axial direction of the carbon nanotubes. The size of the aperture can be the diameter of the hole or width of the gap, and the average aperture size can be in a range from about 10 nm to about 500 μm, for example, about 50 nm, 100 nm, 500 nm, 1 μm, 10 μm, 80 μm or 120 μm. The hole-shaped apertures and the gap-shaped apertures can exist in the patterned carbon nanotube layer at the same time. The sizes of the apertures within the same carbon nanotube layer can be different. The smaller the size of the apertures, the less dislocation defects will occur during the process of growing first semiconductor layer **120**. In one embodiment, the sizes of the apertures are in a range from about 10 nm to about 10 μm.

The carbon nanotubes of the carbon nanotube layer can be orderly arranged to form an ordered carbon nanotube structure or disorderly arranged to form a disordered carbon nanotube structure. The term 'disordered carbon nanotube structure' includes, but is not limited to, a structure where the carbon nanotubes are arranged along many different directions, and the aligning directions of the carbon nanotubes are random. The number of the carbon nanotubes arranged along each different direction can be substantially the same (e.g. uniformly disordered). The disordered carbon nanotube structure can be isotropic. The carbon nanotubes in the disordered carbon nanotube structure can be entangled with each other. The term 'ordered carbon nanotube structure' includes, but is not limited to, a structure where the carbon nanotubes are arranged in a consistently systematic manner, e.g., the carbon nanotubes are arranged approximately along a same direction and/or have two or more sections within each of which the carbon nanotubes are arranged approximately along a same direction (different sections can have different directions).

In one embodiment, the carbon nanotubes in the carbon nanotube layer are arranged to extend along the direction substantially parallel to the surface of the semiconductor layer **102**. In one embodiment, all the carbon nanotubes in the carbon nanotube layer are arranged to extend along the same direction. In another embodiment, some of the carbon nanotubes in the carbon nanotube layer are arranged to extend along a first direction, and some of the carbon nanotubes in the carbon nanotube layer are arranged to extend along a second direction, perpendicular to the first direction.

In one embodiment, the carbon nanotube layer is a free-standing structure and can be drawn from a carbon nanotube array. The term "free-standing structure" means that the carbon nanotube layer can sustain the weight of itself when it is hoisted by a portion thereof without any significant damage to its structural integrity. Thus, the carbon nanotube layer can be suspended by two spaced supports. The free-standing carbon nanotube layer can be laid on the insulating layer **104** directly and easily.

The carbon nanotube layer can be a substantially pure structure of the carbon nanotubes, with few impurities and chemical functional groups. The carbon nanotube layer can be a composite including a carbon nanotube matrix and non-carbon nanotube materials. The non-carbon nanotube materials can be graphite, graphene, silicon carbide, boron nitride, silicon nitride, silicon dioxide, diamond, amorphous carbon, metal carbides, metal oxides, or metal nitrides. The non-carbon nanotube materials can be coated on the carbon nanotubes of the carbon nanotube layer or filled in the apertures. In one embodiment, the non-carbon nanotube materials are coated on the carbon nanotubes of the carbon nanotube layer so the carbon nanotubes can have a greater diameter and the apertures can a have smaller size. The non-carbon nanotube materials can be deposited on the carbon nanotubes of the carbon nanotube layer by CVD or physical vapor deposition (PVD), such as sputtering.

The carbon nanotube layer can include at least one carbon nanotube film, at least one carbon nanotube wire, or a combination thereof. In one embodiment, the carbon nanotube layer can include a single carbon nanotube film or two or more stacked carbon nanotube films. Thus, the thickness of the carbon nanotube layer can be controlled by the number of the stacked carbon nanotube films. The number of the stacked carbon nanotube films can be in a range from about 2 to about 100, for example, about 10, 30, or 50. In one embodiment, the carbon nanotube layer can include a layer of parallel and spaced carbon nanotube wires. The carbon nanotube layer can also include a plurality of carbon nanotube wires crossed or weaved together to form a carbon nanotube net. The distance between two adjacent parallel and spaced carbon nanotube wires can be in a range from about 0.1 μm to about 200 μm. In one embodiment, the distance between two adjacent parallel and spaced carbon nanotube wires can be in a range from about 10 μm to about 100 μm. The size of the apertures can be controlled by controlling the distance between two adjacent parallel and spaced carbon nanotube wires. The length of the gap between two adjacent parallel carbon nanotube wires can be equal to the length of the carbon nanotube wire. It is understood that any carbon nanotube structure described can be used with all embodiments.

In one embodiment, the carbon nanotube layer includes at least one drawn carbon nanotube film. A drawn carbon nanotube film can be drawn from a carbon nanotube array that is able to have a film drawn therefrom. The drawn carbon nanotube film includes a plurality of successive and oriented carbon nanotubes joined end-to-end by van der Waals attractive force therebetween. The drawn carbon nanotube film is a free-standing film. Referring to FIG. 2, each drawn carbon nanotube film includes a plurality of successively oriented carbon nanotube segments joined end-to-end by van der Waals attractive force therebetween. Each carbon nanotube segment includes a plurality of carbon nanotubes parallel to each other, and combined by van der Waals attractive force therebetween. Some variations can occur in the drawn carbon nanotube film. The carbon nanotubes in the drawn carbon nanotube film are oriented along a preferred orientation. The drawn carbon nanotube film can be treated with an organic solvent to increase the mechanical strength and toughness, and reduce the coefficient of friction of the drawn carbon nanotube film. A thickness of the drawn carbon nanotube film can range from about 0.5 nm to about 100 μm.

Referring to FIG. 3, the carbon nanotube layer can include at least two stacked drawn carbon nanotube films. In other embodiments, the carbon nanotube layer can include two or more coplanar carbon nanotube films, and each coplanar carbon nanotube film can include multiple layers. Additionally, if the carbon nanotubes in the carbon nanotube film are aligned along one preferred orientation (e.g., the drawn carbon nanotube film), an angle can exist between the orientation of carbon nanotubes in adjacent films, whether stacked or adjacent. Adjacent carbon nanotube films are combined by the van der Waals attractive force therebetween. An angle between the aligned directions of the carbon nanotubes in two adjacent carbon nanotube films can range from about 0 degrees to about 90 degrees. If the angle between the aligned directions of the carbon nanotubes in adjacent stacked drawn carbon nanotube films is larger than 0 degrees, a plurality of micropores is defined by the carbon nanotube layer. In one embodiment, the carbon nanotube layer shown with the angle between the aligned directions of the carbon nanotubes in adjacent stacked drawn carbon nanotube films is 90 degrees. Stacking the carbon nanotube films will also add to the structural integrity of the carbon nanotube layer.

The carbon nanotube wire can be untwisted or twisted. Treating the drawn carbon nanotube film with a volatile organic solvent can form the untwisted carbon nanotube wire. Specifically, the organic solvent is applied to soak the entire surface of the drawn carbon nanotube film. During the soaking, adjacent parallel carbon nanotubes in the drawn carbon nanotube film will bundle together, due to the surface tension of the organic solvent as it volatilizes. Thus, the drawn carbon nanotube film will be shrunk into untwisted carbon nanotube wire. Referring to FIG. 4, the untwisted carbon nanotube wire includes a plurality of carbon nanotubes substantially oriented along a same direction (i.e., a direction along the length of the untwisted carbon nanotube wire). The carbon nanotubes are parallel to the axis of the untwisted carbon nanotube wire. Specifically, the untwisted carbon nanotube wire includes a plurality of successive carbon nanotube segments joined end to end by van der Waals attractive force therebetween. Each carbon nanotube segment includes a plurality of carbon nanotubes substantially parallel to each other, and combined by van der Waals attractive force therebetween. The carbon nanotube segments can vary in width, thickness, uniformity, and shape. Length of the untwisted carbon nanotube wire can be arbitrarily set as desired. A diameter of the untwisted carbon nanotube wire ranges from about 0.5 nm to about 100 μm.

The twisted carbon nanotube wire can be formed by twisting a drawn carbon nanotube film using a mechanical force to turn the two ends of the drawn carbon nanotube film in opposite directions. Referring to FIG. 5, the twisted carbon nanotube wire includes a plurality of carbon nanotubes helically oriented around an axial direction of the twisted carbon nanotube wire. Specifically, the twisted carbon nanotube wire includes a plurality of successive carbon nanotube segments joined end to end by van der Waals attractive force therebetween. Each carbon nanotube segment includes a plurality of carbon nanotubes parallel to each other, and combined by van der Waals attractive force therebetween. Length of the carbon nanotube wire can be set as desired. A diameter of the twisted carbon nanotube wire can be from about 0.5 nm to about 100 μm. Further, the twisted carbon nanotube wire can be treated with a volatile organic solvent after being twisted. After being soaked by the organic solvent, the adjacent paralleled carbon nanotubes in the twisted carbon nanotube wire will bundle together, due to the surface tension of the organic solvent when the organic solvent volatilizes. The specific surface area of the twisted carbon nanotube wire will decrease, while the density and strength of the twisted carbon nanotube wire will be increased.

The electron collection layer **103** can also be a graphene layer. The graphene layer can include at least one graphene film. The graphene film, namely a single-layer graphene, is a single layer of continuous carbon atoms. The single-layer graphene is a nanometer-thick two-dimensional analog of fullerenes and carbon nanotubes. When the graphene layer includes the at least one graphene film, a plurality of graphene films can be stacked on each other or arranged coplanar side by side. The thickness of the graphene layer can be in a range from about 0.34 nanometers to about 10 micrometers. For example, the thickness of the graphene layer can be 1 nanometer, 10 nanometers, 200 nanometers, 1 micrometer, or 10 micrometers. The single-layer graphene can have a thickness of a single carbon atom. In one embodiment, the graphene layer is a pure graphene structure consisting of graphene. Because the single-layer graphene has great conductivity, thus the electrons can be easily collected and accelerated to the semiconductor layer **102**.

The graphene layer can be prepared and transferred to the substrate by graphene powder or graphene film. The graphene film can also be prepared by the method of chemical vapor deposition (CVD) method, a mechanical peeling method, electrostatic deposition method, a silicon carbide (SiC) pyrolysis, or epitaxial growth method. The graphene powder can prepared by liquid phase separation method, intercalation stripping method, cutting carbon nanotubes, preparation solvothermal method, or organic synthesis method.

In one embodiment, the electron collection layer **103** is a drawn carbon nanotube film having a thickness of 5 nanometers to 50 nanometers. The carbon nanotube film has good tensile conductivity and electron collecting effect. Furthermore, the carbon nanotube film has good mechanical properties, which can effectively improve the lifespan of the electron emission source **10**.

The first electrode **101** is a thin conductive metal film. A material of the first electrode **101** can be gold, platinum, scandium, palladium, or hafnium metal. The thickness of the first electrode **101** can range from about 10 nanometers to about 100 micrometers, such as 10 nanometers, 50 nanometers. In one embodiment, the first electrode **101** is molybdenum film having a thickness of 100 nanometers. Furthermore, the material of the first electrode **101** may also be carbon nanotube layer or graphene layer. The plurality of carbon nanotubes in the carbon nanotube layer form a conductive network. The carbon nanotube layer can also define a plurality of apertures. Thus the electrons can be easily escaped from the first electrode **101**. The material of the second electrode **105** can be same as the first electrode **101**.

The electron emission source **10** works in the alternating current (AC) driving mode. The working principle of the electron emission source **10** is: in the negative half cycle, the potential of the second electrode **105** is high, and the electrons are injected into the semiconductor layer **102** from the first electrode **101**. While the electrons reach the electron collection layer **103**, the electrons will be collected and stored in the electron collection layer **103**. An interface between the electron collection layer **103** and insulating layer **104** forms an interface state. In the positive half cycle, due to the higher potential of the carbon nanotube layer of the first electrode **101**, the electrons stored on the interface state are pulled to the semiconductor layer **102** and accelerated in the semiconductor layer **102**. Because the semiconductor layer **102** is in contact with the first electrode **101**, a part of high-energy electrons can rapidly pass through the carbon nanotube layer of the first electrode **101**.

Referring to FIG. **6**, a method of making electron emission source **10** comprises:

(S**11**) locating a second electrode **105** on a surface of a substrate **106**;

(S**12**) depositing an insulating layer **104** on the second electrode **105**;

(S**13**) applying an electron collection layer **103** on the insulating layer **104**;

(S**14**) locating a semiconductor layer **102** on the electron collection layer **103**; and

(S**15**) applying a first electrode **101** on the semiconductor layer **102**.

In step (S**11**), the substrate **106** can be rectangular. The material of the substrate **106** can be insulating material such as glass, ceramic, or silicon dioxide. In one embodiment, the substrate **106** is a silicon dioxide.

The preparation method of the second electrode **105** can be magnetron sputtering method, vapor deposition method, or an atomic layer deposition method. In one embodiment, the second electrode **105** is the molybdenum metal film formed by vapor deposition, and the thickness of the second electrode **105** is about 100 nanometers.

In step (S**12**), the preparation method of the insulating layer **104** can be the magnetron sputtering method, the vapor deposition method, or the atomic layer deposition method. In one embodiment, the insulating layer **104** is tantalum oxide formed by atomic layer deposition method, and the thickness of the insulating layer **104** is about 100 nanometers.

In step (S**13**), the method of forming the electron collector layer **103** can be selected according to the material. While the material of the electron collector layer **103** is metal or metal alloy, the electron collection layer **103** can be formed by magnetron sputtering, vapor deposition, or atomic layer deposition. While the electron collector layer **103** comprises carbon nanotube layer, the electron collection layer **103** can be formed by directly locating a drawn carbon nanotube film, a flocculate carbon nanotube film, or a pressed carbon nanotube film on the insulating layer **104**. While the material of the electron collector layer **103** is graphene, the electron collection layer **103** can be formed by applying a graphene layer on the insulating layer **104**. In one embodiment, the electron collection layer **103** is formed by directly locating a carbon nanotube film drawn from a carbon nanotube array. The thickness of the electron collector layer **103** ranges from about 5 nanometers to about 50 nanometers.

In step (S**14**), the method of forming semiconductor layer **102** can be similar to the method of forming the insulating layer **104**. In one embodiment, the semiconductor layer **102** is zinc sulfide layer formed by a vapor deposition method, and the thickness of the semiconductor layer **102** is about 50 nanometers.

In step (S**15**), the method of forming the first electrode **101** can be same as the method of forming the electron collection layer **103**. In one embodiment, the drawn carbon nanotube film is applied as the first electrode **101**.

The electron emission source **10** can have the following advantages. The electron collection layer **103** is located between the semiconductor layer **102** and the insulating layer **104**, thus the electron collection layer **103** can effectively collect and store the electrons between the semiconductor layer **102** and the insulating layer **104**, and the electron emission efficiency of the electron emission source **10** can be improved compared to the traditional MISM electron emission source.

Referring to FIG. **7**, an electron emission source **20** of one embodiment comprises a first electrode **101**, a semiconductor layer **102**, an electron collection layer **103**, an insulating layer **104**, and a second electrode **105** stacked in that sequence. Furthermore, a pair of bus electrodes **107** is located on the first electrode **101**.

The structure of electron emission source **20** is similar to the structure of electron emission source **10**, except that the pair of bus electrodes **107** is located on the first electrode **101**.

The pair of bus electrodes **107** are spaced from each other and electrically connected to the first electrode **101** in order to supply current. Each bus electrode **107** is a bar-shaped electrode.

While the first electrode **101** comprises the plurality of carbon nanotubes, the pair of bus electrodes **107** can be applied on the two opposite sides of the first electrode **101** along the extending direction of the carbon nanotubes. The extending direction of the bar-shaped bus electrode **107** is perpendicular to the extending direction of the plurality of carbon nanotubes of the first electrode **101**. Thus the current can be uniformly distributed in the first electrode **101**.

A shape of the bus electrode **107** can be bar-shaped, square, triangular, rectangular, etc. A material of the bus electrode **107** can be gold, platinum, scandium, palladium, hafnium, or metal alloy. In one embodiment, the bus electrode **107** is bar-shaped platinum electrode. The pair of bar-shaped bus electrodes **107** are parallel with and spaced from each other.

Referring to FIG. **8**, an electron emission device **300** of one embodiment comprises a plurality of electron emission units **30**. Each of the plurality of electron emission units **30** comprises a first electrode **101**, a semiconductor layer **102**, an electron collection layer **103**, an insulating layer **104**, and a second electrode **105** stacked in that sequence. The insulating layers **104** in the plurality of electron emission units **30** are in contact with each other and form a continuous layer. The electron emission device **300** can be located on a substrate **106**.

The electron emission unit **30** is similar to the electron emission source structure **10** described above, except that the plurality of electron emission units **30** share the common insulating layer **104**. The plurality of electron emission units **30** can work independently from each other. In detail, the first electrodes **101** in adjacent two of the plurality of electron emission units **30** are spaced apart from each other, the semiconductor layers **102** in adjacent two of the plurality of electron emission units **30** are spaced apart from each other, and the second electrodes **105** in adjacent two of the plurality of electron emission units **30** are also spaced apart from each other. In one embodiment, a distance between adjacent two semiconductor layers **102** is about 200 nanometers, a distance between adjacent two first electrodes **101** is about 200 nanometers, and a distance between the adjacent two electrodes **105** is about 200 nanometers.

An embodiment of a method of making electron emission device **300** comprises:

(S21) locating a plurality of second electrodes **105** on a surface of a substrate **106**, wherein the plurality of second electrodes **105** are spaced from each other;

(S22) depositing an insulating layer **104** on the plurality of second electrodes **105**;

(S23) applying an electron collection layer **103** on the insulating layer **104**;

(S24) forming a plurality of semiconductor layer **102** by locating a semiconductor layer preform on the electron collection layer **103** and patterning the semiconductor layer preform; and

(S25) applying a plurality of first electrodes **101** on the plurality of semiconductor layer **102**.

The method of making the electron emission device **300** is similar to the method of making the electron emission source **10**, except that the plurality of second electrodes **105** is applied on the substrate **106** and spaced from each other.

In step (**S21**), the method of forming the plurality of second electrodes **105** can be screen printing method, magnetron sputtering method, vapor deposition method, atomic layer deposition method. In one embodiment, the plurality of second electrodes **105** are formed via the vapor deposition method comprising:

providing a mask layer having a plurality of openings;
deposing a conductive layer on the mask layer; and
removing the mask layer.

The material of the mask layer can be polymethyl methacrylate (PMMA) or silicone compound (HSQ). The size and the position of the openings in the mask layer can be selected according to the requirement of the distribution of the plurality of electron emitting units **30**. In one embodiment, the material of the second electrode **105** is molybdenum. The number of the second electrode **105** is 16, and the number of the electron emission unit **30** is also 16.

In step (**S25**), the method for forming the first electrode **101** can be selected according to the material of the first electrode **101**. While the material of the first electrode **101** is conductive metal, the first electrode can be formed by sputtering, atomic layer deposition, vapor deposition method. While the first electrode **101** is graphene or carbon nanotubes, the first electrode **101** can be formed by chemical vapor deposition. The carbon nanotube layer or graphene membrane is etched to form the first electrodes **101** spaced apart.

In step (**S24**), the semiconductor layer preform can be patterned via plasma etching, laser etching, or wet etching. In one embodiment, the semiconductor layer preform is patterned according to the distribution of the first electrode **101**. Thus each of the plurality of electron emission units **30** comprises one electrode **101**, one semiconductor layer **102**, and one second electrode **105**.

Furthermore, the electron collection layer **103** can also be patterned. Thus the first electrode **101**, the semiconductor layer **102**, the electron collection layer **103**, and the second electrode **105** in the plurality of electron emission units **30** are spaced from each other. The plurality of electron emission units **30** share common insulating layer **104**. The electron collection layer **103** can be patterned by plasma etching method, laser etching method, or wet etching method.

Referring to FIGS. **9-10**, an electron emission device **400** of one embodiment comprises a plurality of electron emission units **40**, a plurality of row electrodes **401**, and a plurality of column electrodes **402** on a substrate **106**. Each of the plurality of electron emission units **40** comprises a first electrode **101**, a semiconductor layer **102**, an electron collection layer **103**, an insulating layer **104**, and a second electrode **105** stacked in that sequence. The insulating layers **104** in the plurality of electron emission units **40** are connected with each other to form a continuous layered structure.

The electron emission device **400** is similar to the electron emission device **300**, except that the electron emission device **400** further comprises the plurality of row electrodes **401** and the plurality of column electrodes **402** electrically connected to the plurality of electron emission units **40**.

The plurality of row electrodes **401** is parallel with and spaced from each other. Similarly, the plurality of column electrodes **402** are parallel with and spaced from each other. The plurality of column electrodes **402** are insulated from the plurality of row electrodes **402** through the insulating layer **104**. The adjacent two row electrodes **401** are intersected with the adjacent two row electrodes **401** to form a grid.

A section is defined between the adjacent two row electrodes **401** and the adjacent two column electrodes **402**. The electron emission unit **40** is received in one of sections and electrically connected to the row electrode **401** and the column electrode **402**. The row electrode **401** and the column electrode **402** can electrically connect to the electron emission unit **40** via two electrode leads **403** respectively to supply current for the electron emission unit **40**.

In one embodiment, the plurality of column electrodes **402** are perpendicular to the plurality of row electrodes **401**.

The plurality of electron emission units **40** form an array with a plurality of rows and columns. The plurality of first electrodes **101** in the plurality of electron emission units **40** are spaced apart from each other. The plurality of second electrodes **105** in the plurality of electron emission units **40** are also spaced apart from each other. The plurality of semiconductor layers **102** in the plurality of electron emission units **40** can be spaced apart from each other.

In one embodiment, the plurality of electron collection layer **103** in the plurality of electron emission units **40** can connect to each other to form an integrated structure. It means that the plurality of electron collection layer **103** form a continuous layered structure, and the plurality of electron emission units **40** share a common electron collection layer **103**.

Referring to FIG. **11**, an electron emission display **500** of one embodiment comprises a substrate **106**, a plurality of electron emission units **40** on the substrate **106**, and an anode structure **510**. The plurality of electron emission units **40** are spaced from the anode structure **510** and face to the anode structure **510**.

The anode structure **510** comprises a glass substrate **512**, an anode **514** on the glass substrate **512**, and phosphor layer **516** coated on the anode **514**. The anode structure **510** is supported by an insulating support **518**. The substrate **106**, the glass substrate **512**, and the insulating support **518** form a sealed space. The anode **514** can be indium tin oxide (ITO) film. The phosphor layer **516** face to the plurality of electron emission units **40**.

In detail, the phosphor layer **516** face to the first electrode **101** to receive electrons emitted from the first electrode **101**. In application, different voltages are applied to the first electrode **101**, the second electrode **105**, and the anode **514** of the electron emission display **500**. In one embodiment, the second electrode **105** is at the ground or zero voltage, the voltage applied on the first electrode **101** is several tens of volts, and the voltage applied on the anode **514** is a few hundred volts. The electrons emitted from the first electrode **101** of the electron emission unit **40** are driven under the electric filed to move toward the phosphor layer **516**. The electrons eventually reaches the anode structure **510** and bombarded the phosphor layer **516** coated on the anode **514**. Thus fluorescence can be activated from the phosphor layer **516**. Referring to FIG. **12**, the electrons in the electron emission display **500** are uniformly emitted, and the electron emission display **500** has better luminous intensity.

Referring to FIGS. **13** and **14**, an electron emission device **600** of one embodiment comprises a plurality of first electrodes **1010** spaced from each other, a plurality of second electrodes **1050** spaced from each other. The plurality of first electrodes **1010** are bar-shaped and extend along a first direction, and the plurality of second electrodes **1050** are bar-shaped and extend along a second direction that intersects with the first direction. The plurality of first electrodes **1010** are intersected with the plurality of second electrodes **1050**. A semiconductor layer **102**, an electron collection layer **103**, and an insulating layer **104** are stacked together and sandwiched between the first electrode **1010** and the second electrode **1050** at intersections of the first electrode **1010** and the second electrode **1050**. The first electrode **1010** is located on the semiconductor layer **102**.

The electron emission device **600** is similar to the electron emission device **400**, except that the electron emission device **600** comprises the plurality of bar-shaped first electrodes **1010** and the plurality of bar-shaped second electrodes **1050**.

The first direction can be defined as the X direction, and the second direction can be defined as the Y direction that intersects with the X direction. The Z direction is defined as a third direction perpendicular to both the X direction and Y direction. The plurality of first electrodes **1010** are aligned along a plurality of rows, and the plurality of second electrodes **1050** are aligned along a plurality of columns. Thus the plurality of first electrodes **1010** and the plurality of second electrodes **1050** are overlapped with each other at the plurality of intersections. An electron emission unit **60** is formed at each intersection in the electron emission device **600**. The electron emission unit **60** comprises the semiconductor layer **102**, the electron collection layer **103**, and the insulating layer **104** sandwiched between the first electrode **1010** and the second electrode **1050** at the intersection, and the semiconductor layer **102** is in contact with the first electrode **1010**.

The plurality of electron emission units **60** can be spaced from each other and aligned along a plurality of rows and a plurality of columns. The semiconductor layers **102** in the plurality of electron emission units **60** are also spaced apart from each other. The plurality of semiconductor layers **102** aligned along the same row are electrically connected to the same first electrode **101**. The plurality of semiconductor layers **102** aligned along the same column are electrically connected to the same second electrode **105**. Thus the plurality of electron emission units **60** aligned along the same rows share the same first electrode **101**, and the plurality of electron emission units **60** aligned along the same columns share the same second electrode **105**.

Furthermore, the plurality of electron emission units **60** can share a common electron collection layer **103**. The plurality of electron emission units **60** can also share a common insulating layer **104**. In one embodiment, the electron collection layer **103** in the plurality of electron emission units **60** are spaced apart from each other, and the insulating layer **104** in the plurality of electron emission units **60** are also spaced apart from each other.

While a voltage is applied between the first electrode **1010** and the second electrode **1050**, the electrons can be emitted from each of the plurality of electron emission units **60** at the intersections.

In application, different voltages can be applied to the first electrode **1010**, the second electrode **1050**, and the anode **514**. The second electrode **1050** can be applied with a ground or zero voltage, the voltage applied on the first electrode **1010** can be tens of volts to hundreds of volts. An electric field is formed between the first electrode **1010** and the second electrode **1050** at the intersection. The electrons pass through the semiconductor layer **102** and emit from the first electrode **1010**.

An embodiment of a method of making electron emission device **600** comprises:

(S**31**) forming a plurality of second electrodes **1050** on a surface of a substrate **106**, wherein the plurality of second electrodes **1050** are spaced from each other and extend along a first direction;

(S**32**) depositing an insulating layer **104** on the plurality of second electrodes **1050**;

(S**33**) applying an electron collection layer **103** on the insulating layer **104**;

(S**34**) forming a plurality of semiconductor layers **102** by locating a semiconductor preform on the electron collection layer **103** and patterning the semiconductor layer preform; and

(S**25**) applying a plurality of first electrodes **1010** on the plurality of semiconductor layer **102** according to the plurality of second electrodes **105**, wherein the plurality of first electrodes **1010** are spaced from each other and extend along a second direction.

The method of making electron emission device **600** in present embodiment is similar to the method of making electron emission device **300**. The first direction can be intersected with the second direction.

Furthermore, the electron collection layer **103** and the insulating layer **104** can also be patterned according the patterned structure of the first electrode **1010**.

Referring to FIG. **15**, an electron emission display **700** of one embodiment comprises a substrate **106**, an electron emission device **600** located on the substrate **106**, and an anode structure **510** spaced from the electron emission device **600**. The electron emission device **600** comprises a plurality of electron emission units **60**.

The electron emission display **700** is similar to the electron emission display **500**, except that the plurality of first electrodes **101** are connected with each other to form a plurality of bar-shaped first electrodes **1010** along a first direction. Furthermore, the plurality of second electrodes **105** are connected with each other to form the plurality of second electrodes **1050** along a second direction.

The electrons emitted from the surface of the first electrodes **1010** at the intersection and bombard the phosphor layer **516** coated on the anode **514**. Thus fluorescence is generated from the electron emission display **700**.

Depending on the embodiment, certain of the steps of methods described may be removed, others may be added, and the sequence of steps may be altered. It is also to be understood that the description and the claims drawn to a method may include some indication in reference to certain steps. However, the indication used is only to be viewed for identification purposes and not as a suggestion as to an order for the steps.

It is to be understood that the above-described embodiments are intended to illustrate rather than limit the disclosure. Variations may be made to the embodiments without departing from the spirit of the disclosure as claimed. It is understood that any element of any one embodiment is considered to be disclosed to be incorporated with any other embodiment. The above-described embodiments illustrate the scope of the disclosure but do not restrict the scope of the disclosure.

What is claimed is:

1. An electron emission device, comprising:

a plurality of first electrodes substantially parallel to each other and extending along a first direction;

a plurality of second electrodes substantially parallel to each other and extending along a second direction, wherein the plurality of second electrodes intersect with the plurality of first electrodes to define a plurality of intersections; and

a plurality of electron emission units; wherein each electron emission unit is sandwiched between one of the plurality of first electrodes and one of the plurality of second electrodes at each of the plurality of intersections; wherein the electron emission unit comprises a semiconductor layer, an electron collection layer, and an insulating layer stacked together; and the electron collection layer is a conductive layer.

2. The electron emission device of claim **1**, wherein the first direction is perpendicular to the second direction.

3. The electron emission device of claim **1**, wherein the plurality of first electrodes allows electrons to pass through at the plurality of intersections.

4. The electron emission device of claim **1**, wherein each semiconductor layer in the plurality of electron emission units are spaced apart from each other.

5. The electron emission device of claim **4**, wherein each insulating layer in the plurality of electron emission units are spaced apart from each other.

6. The electron emission device of claim **4**, wherein each electron collection layer in the plurality of electron emission units are spaced apart from each other.

7. The electron emission device of claim **4**, wherein each electron collection layer in the plurality of electron emission units are in contact with each other to form a continuous structure.

8. The electron emission device of claim **1**, wherein a material of the electron collection layer is selected from the group consisting of gold, platinum, scandium, palladium, hafnium, carbon nanotube, and graphene.

9. The electron emission device of claim **1**, wherein the electron collection layer comprises a carbon nanotube layer.

10. The electron emission device of claim **9**, wherein the carbon nanotube layer is a free-standing structure.

11. The electron emission device of claim **9**, wherein the carbon nanotube layer comprises a plurality of carbon nanotubes joined end to end by van der Waals force.

12. The electron emission device of claim **1**, wherein the electron collection layer comprises a carbon nanotube film or a carbon nanotube wire.

13. The electron emission device of claim **1**, wherein the electron collection layer comprises a plurality of carbon nanotube films stacked together.

14. The electron emission device of claim **1**, wherein the electron collection layer comprises a plurality of carbon nanotube wires parallel to or intersected with each other.

15. The electron emission device of claim **1**, wherein the electron collection layer comprises a graphene layer.

16. The electron emission device of claim **1**, wherein each of the plurality of first electrodes comprises a carbon nanotube layer.

17. The electron emission device of claim **16**, wherein the carbon nanotube layer comprises a plurality of carbon nanotubes electrically connected with each other.

18. The electron emission device of claim **16**, wherein the carbon nanotube layer defines a plurality of apertures.

19. An electron emission display, comprising:

a substrate;

an electron emission device located on the substrate, wherein the electron emission device comprises:

a plurality of first electrodes substantially parallel to each other;

a plurality of second electrodes substantially parallel to each other, wherein the plurality of second electrodes intersect with the plurality of first electrodes to define a plurality of intersections; and

a plurality of electron emission units; wherein each electron emission unit is sandwiched between one of the plurality of first electrodes and one of the plurality of the second electrodes at each of the plurality of intersections; wherein each electron emission unit comprises a semiconductor layer, an electron collection layer, and an insulating layer stacked together; and the electron collection layer is a conductive layer;

an anode structure spaced from the electron emission device, wherein the anode structure comprises an anode and a phosphor layer coated on the anode, and the phosphor layer faces to the electron emission device.

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